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Bending Tests on Wood, Steel and Worn Rail Catenary Masts

prepared for
Transportation Development Centre
Transport Canada

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Canadian Pacific
Consulting Services Ltd.

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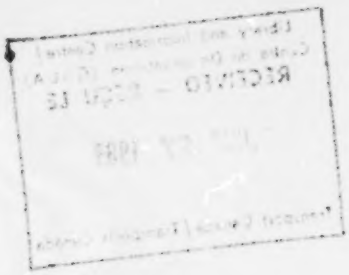

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17. Abstract

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17. Résumé

Ce rapport rend compte des résultats de l'étude sur les déformations latérales subies par les poteaux de caténaire d'une ligne ferroviaire électrifiée. L'essai portait sur six poteaux dont deux en bois, deux en acier (modèles U-100 et U-120) et deux en rails récupérés. L'effort de flexion était appliqué à 1,1 mètre du sommet du poteau afin de simuler les moments fléchissants exercés par les fils et les potences les supportant, et la flèche des poteaux a été mesurée à deux mètres de leur sommet. Ces derniers étaient fixés au massif de fondation au moyen d'un collier de serrage.

Le poteaux faits de rails récupérés ont présenté la plus faible flèche, suivis dans l'ordre par les poteaux en acier et ceux en bois. Le premier poteau en rails récupérés est également celui dont la courbe effort-déformation accusait l'hystérésis la plus forte. Les valeurs d'hystérésis étaient très faibles dans le cas des poteaux en bois, tandis que celles caractérisant les courbes effort-déformation des poteaux en acier se situaient entre celles des deux autres matériaux.

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SUMMARY

This report is an investigation of the lateral deflections experienced by catenary poles in an electrified railway operation. Six poles were tested. These include two wood, two steel (U-100 and U-120 designs) and two salvage rail masts. Loads were applied at 1.1 m from the top of the mast in order to simulate the bending moments of wires and supporting cantilevers. Pole deflections were then measured at 2 m from the top. Clamps were used to act as foundation support.

The salvage rail masts had the smallest deflection rates, followed by steel and wood poles respectively. The Alternative I salvage rail mast also had the largest hysteresis in its load-deflection relationship. Wood poles showed very little hysteresis. With steel poles, the hysteresis levels were in between those of salvage rail and wood poles.

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1.0 INTRODUCTION

At the request of Transportation Development Centre of Transport Canada, bending tests were performed on wood, fabricated steel and worn rail catenary masts. Tests were carried out by the National Research Council of Canada in Ottawa. All tests were performed in the vertical plane, except those on the wood poles, which were carried out in both vertical and horizontal planes. It should be noted that deflections measured in the vertical plane correspond to lateral deflections of a catenary mast in actual field situations. Masts were clamped horizontally at the specified distance from the top of the mast. At least four clamps were used to simulate the «built-in» condition of actual catenary masts set in concrete. Clamp spacing for all masts is shown in Figure 1. Deflections were measured from the overhung configuration of the masts.

2.0 SPECIFICATIONS OF THE CATENARY MASTS

For the purpose of constructing an experimental catenary, three wood masts, four Type U-100 and two Type U-120 fabricated steel masts, and 6 worn rail masts (3 of both designs) were supplied to the Railway Laboratory of NRC. Dimensions of the wood masts are given in Table 1, steel fabricated masts are shown in Figure 1, whereas Figures 2 and 3 show Alternative I and Alternative II scrap rail masts respectively.

			CIRCUMFERENCE (cm)					
No.	Weight (kg)	Length (m)	butt	1.83m fr.butt	8.9m fr.top (1)	2.0m fr.top (2)	1.1m fr.top (3)	top
1	608	13.77	102.9	100.0	99.7	8.19	78.4	76.5
2	599	13.91	104.8	98.4	99.1	77.8	78.1	64.8
3	635	13.74	104.8	105.4	98.4	77.5	74.9	68.6

Table 1 - Wood Mast Specifications

Notes:
(1) End of «free» cantilever length
(2) Point of deflection measurements
(3) Point of load application

3.0 METHODOLOGY

3.1 TEST SPECIFICATIONS

3.1.1 Wood Masts

Measure and record circumferences at top and 1.8 m from the butt of the pole; also its length. Obtain a bending moment of 24.5 kNm with a single force applied 1.1 m from top and pole restrained at 8.9 m from the top. Remaining portion of the butt shall be restrained so as to simulate the support that would be provided by a foundation.

3.1.2 Steel Fabricated Masts Types U-100 and U-120

Obtain a bending moment of 38.8 kNm and 58.4 kNm applied to U-100 and U-120 poles respectively. A single force of 4670 N and 7040 N applied at 1.1 m from the top and pole restrained at 9.3 m from the top so as to simulate the support that would be provided by a foundation. Deflection shall be measured at a point 2 m from the top.

3.1.3 Worn Rail Masts Alternatives I and II

Obtain a bending moment of 41 kNm with single force of 5000 N applied 1.1 m from top of mast and mast restrained at 9.3 m from top. Remaining portion of butt shall be restrained so as to simulate the support that would be provided by a foundation. Deflection shall be measured at a point 2 m from top.

3.2 TEST DESCRIPTION

Deflections of two wood, two steel fabricated (Types U-100 and U-120), and two worn rail. (Alternatives I and II) masts were clamped horizontally to simulate the built-in end condition of a catenary mast set in a concrete base. The wood poles were clamped with the butt end larger

axis oriented horizontally. The steel fabricated and the scrap rail masts had their planes of maximum rigidity oriented vertically, i.e. the bending moment caused by a vertically applied load was acting in the plane of maximum rigidity. Loads were applied vertically upward with an overhead travelling crane (see Figures 4 and 5). The wood masts were also bent in the horizontal plane as shown in Figure 6. Deflections were measured with a potentiometer type extensometer, and the loads with a load cell. Both deflection and load at each loading step were recorded on a chart.

It should be noted that the steel fabricated masts were strengthened at the support with diagonal compression braces to reduce shearing stresses, and thus to minimize relative displacement between the top and bottom legs (see Figure 1). The first tested Type U-100 mast (not shown in Table 2) developed fatigue cracks near the welded joints. As these did not develop in the other U-100 mast tested, it is felt the cracks may be the result of poor construction and do not indicate a design flaw. Figure 7 illustrates one of the fatigue cracks.

Each bending cycle was repeated three times. In all cases reproducibility of deflections was good.

4.0 RESULTS

Summary of test results is given in Table 2. Linear load-deflection relationships were assumed for all masts. This assumption accounts for deflections due to gravity.

Whereas worn rail masts have the smallest deflection rates, their weight exceeds that of wood masts two times and that of steel fabricated U-100 masts five times. Practically no hysteresis was noted when bending the wood masts. This cannot be said about the steel fabricated or the worn rail masts. The Alternative I worn rail mast had the largest hysteresis, most likely on account of the fewer number of shear-carrying joints (see Figure 8). For comparison purposes, the deflection curve of the Alternative II worn rail mast is shown in Figure 9. Hysteresis of the steel fabricated masts are approximately twice as large as this one.

The larger the hysteresis, the greater damping and, therefore, less tendency to vibrate like a reed.

Curves were drawn for the worn rail masts to illustrate the characteristic only. Reference was made to the magnitude in wood poles and fabricated steel masts for comparison purposes.

The theoretical formula, developed in Figure 9 - «Deflection of a Conical Cantilever Beam» has been used to estimate deflections of the wood masts. Based on the modulus of elasticity (E) of 8,500 MPa, the theoretical lateral deflection of mast no. 1 is 118.6 mm and that of mast no. 2 is 129.2 mm, measured at a point 2.0 m from the top of the mast, under an assumed load of 3,141 N applied at a point 1.1 m from the top of the mast.

No.	Type	Weight (kg)	Cantil. Length (m)	Load (N) (1)	DEFLECTION (mm) (2) VERTICAL		HORIZONTAL	
1	Wood	608	8.9	3,141	115.1	(36.6)	119.4	(38.0)
2	Wood	599	8.9	3,141	159.5	(50.8)	160.5	(51.1)
3	St. Fab. U-100	291	9.3	4,670	101.6	(21.8)		
4	St. Fab. U-120	424	9.3	7,040	122.3	(17.4)		
5	Worn Rail Alter. I	1,552	9.3	5,000	66.5	(13.3)		
6	Worn Rail	1,600	9.3	5,000	39.4	(7.9)		

Table 2. Deflections of Catenary Masts

Notes: (1) See Test Specifications

(2) Figures in brackets indicate deflection rates per 1,000 N. In all cases loads were applied at a point 1.1 m from the top of the mast and the deflections were measured at a point 2.0 m from the top.

5.0 CONCLUSIONS

i) Most of the old rail poles cracked where the bolt holes had been drilled. One pole arrived broken. The test pole had to be constructed with undamaged pieces taken from the three samples given.

ii) Rail posts are very heavy. This may cause difficulty in field installation.

iii) Rail posts have the smallest deflection rates and the largest hysteresis.

iv) Rail posts are more unsightly than the other two types.

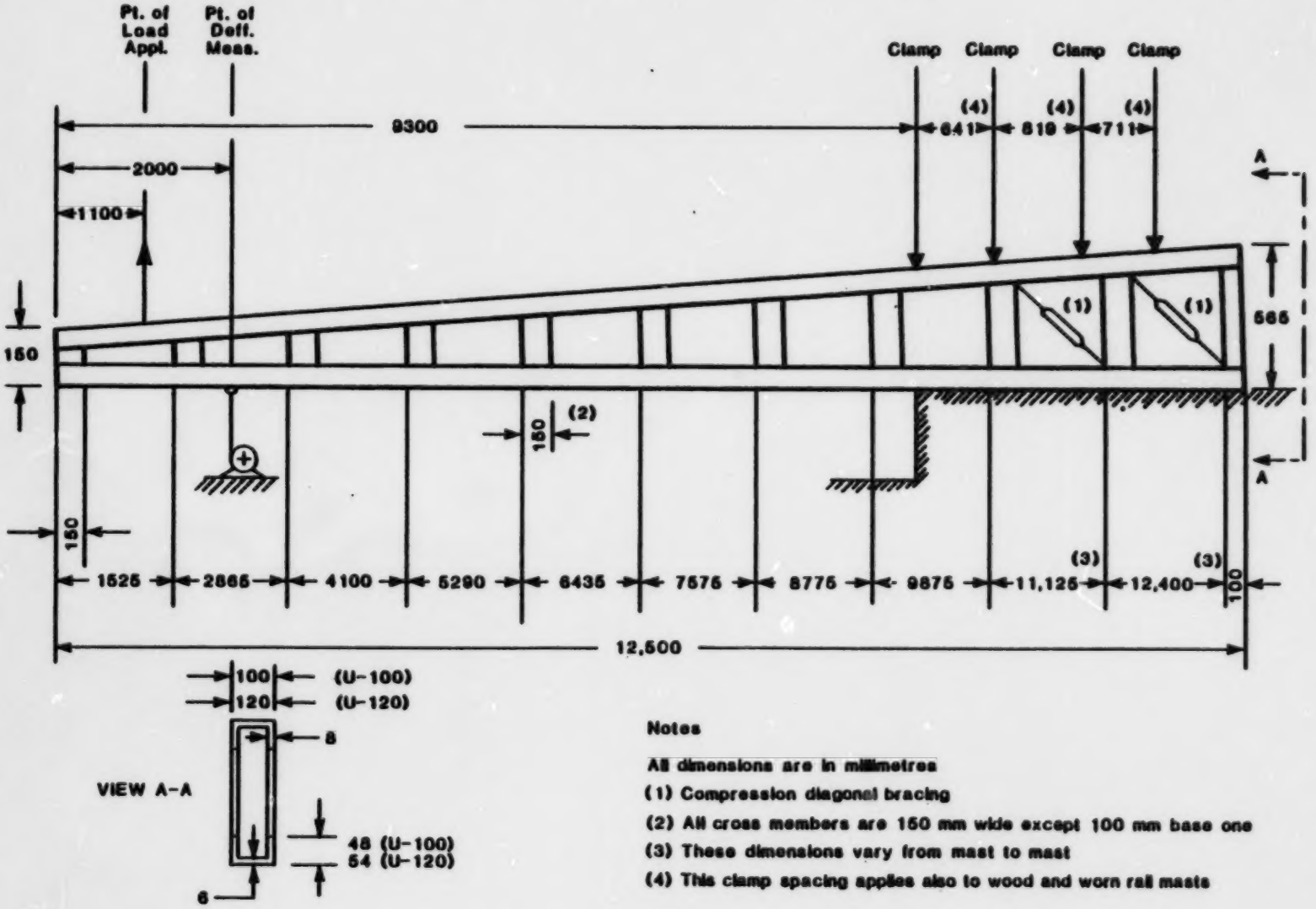
v) Wood poles are very irregular in shape. Again, this may pose a problem in installation.

vi) Wood poles showed the maximum deflection rates with no hysteresis.

vii) Other projects have shown costs for wood poles to be greater than that for fabricated steel poles.

viii) For most applications, the steel fabricated poles give the best cost/performance ratio.

Figure 1
STEEL FABRICATED CATENARY MASTS
TYPES U-100 AND U-120



Notes

All dimensions are in millimetres

(1) Compression diagonal bracing

(2) All cross members are 150 mm wide except 100 mm base one

(3) These dimensions vary from mast to mast

(4) This clamp spacing applies also to wood and worn rail masts

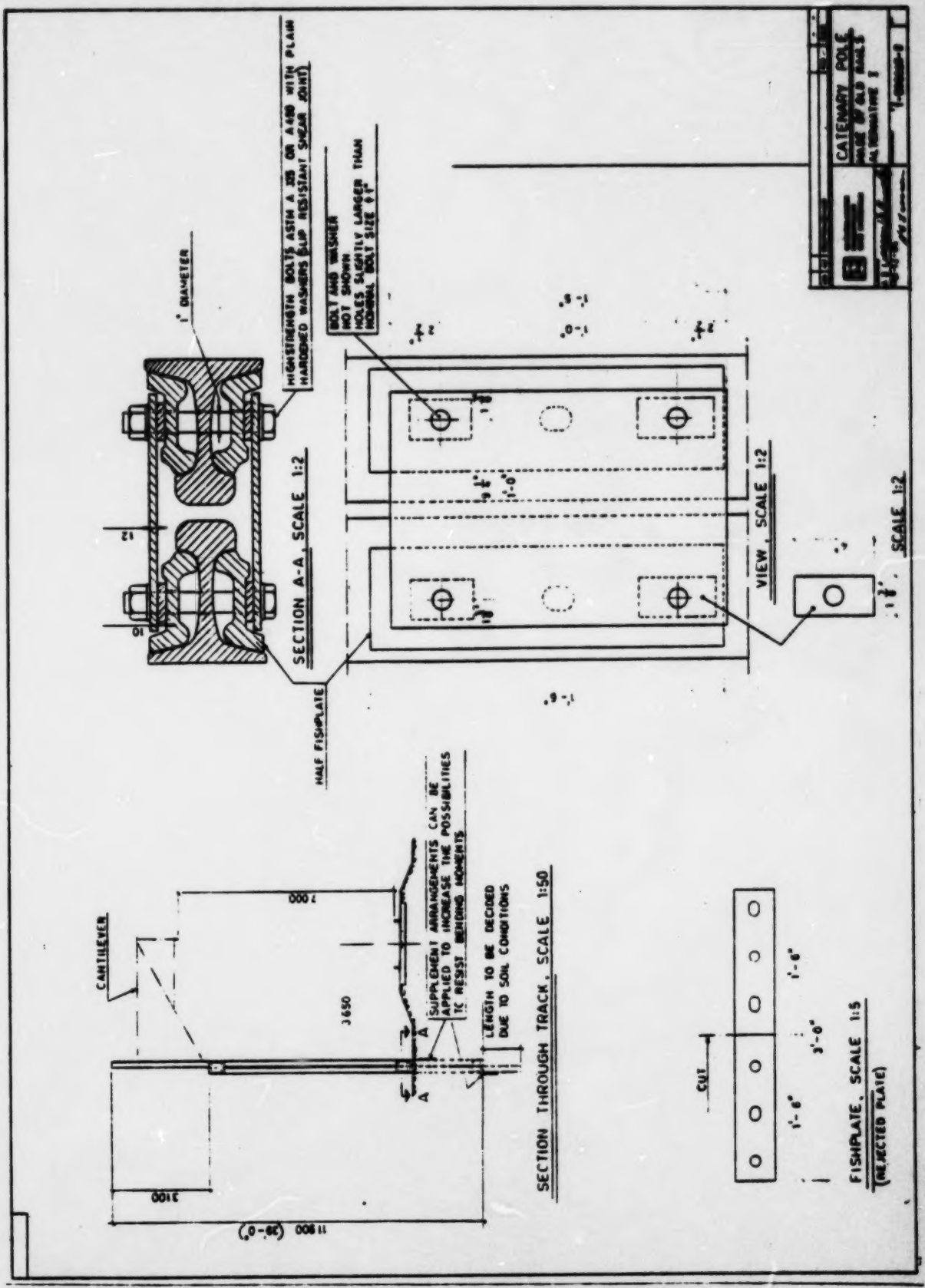


Figure 2. Alternative I Worn Rail Catenary Mast

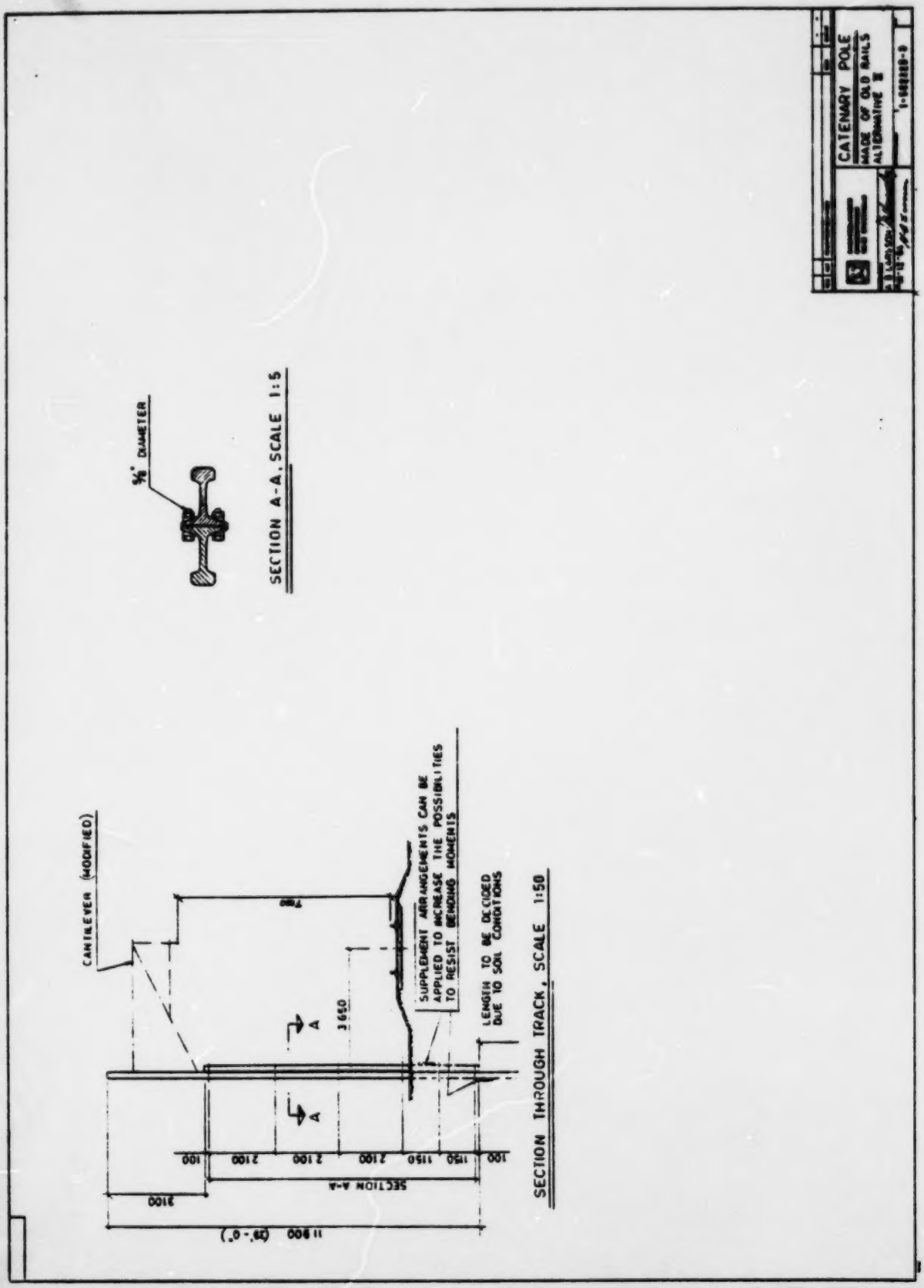


Figure 3. Alternative II Worn Rail Catenary Mast

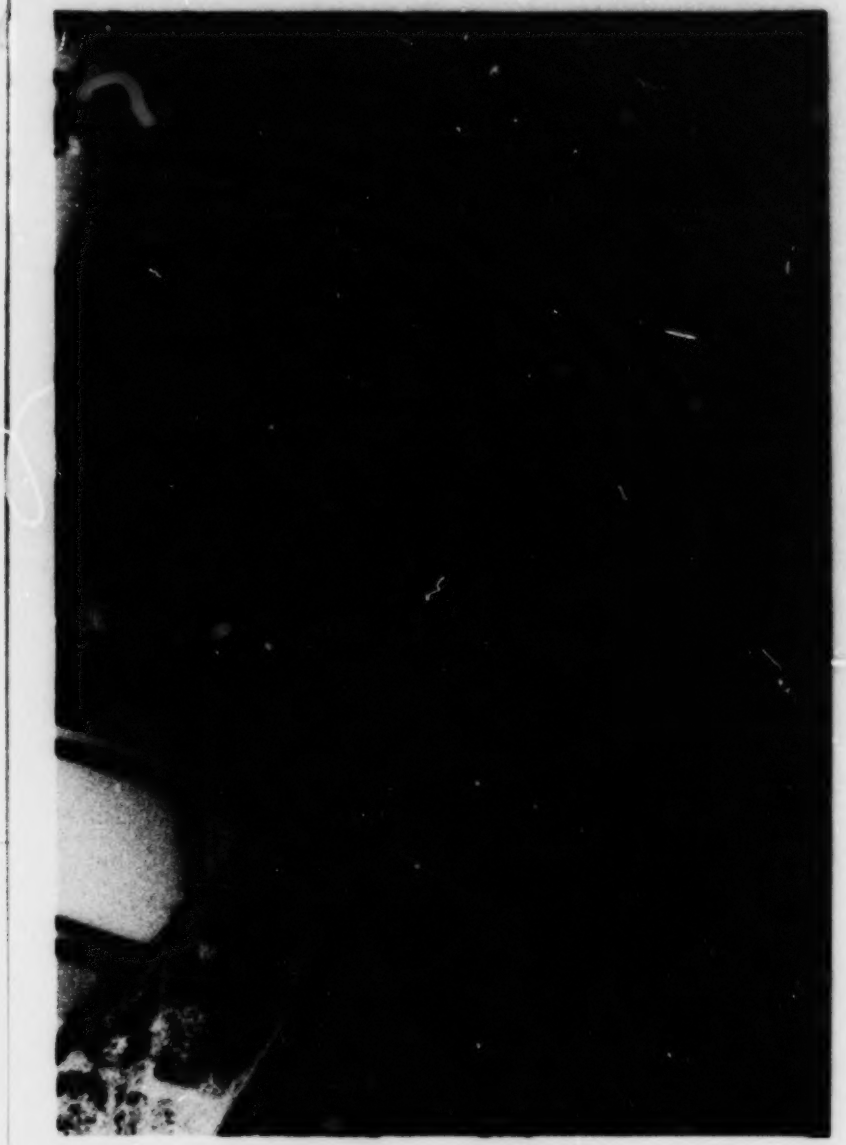


Figure 4. An Alternative I Worn Rail Catenary Mast Clamped Horizontally in the Vertical Plane of Maximum Flexural Rigidity, to Simulate the Built-in End Condition of a Cantilever. Clamp spacing is given in Figure 1.

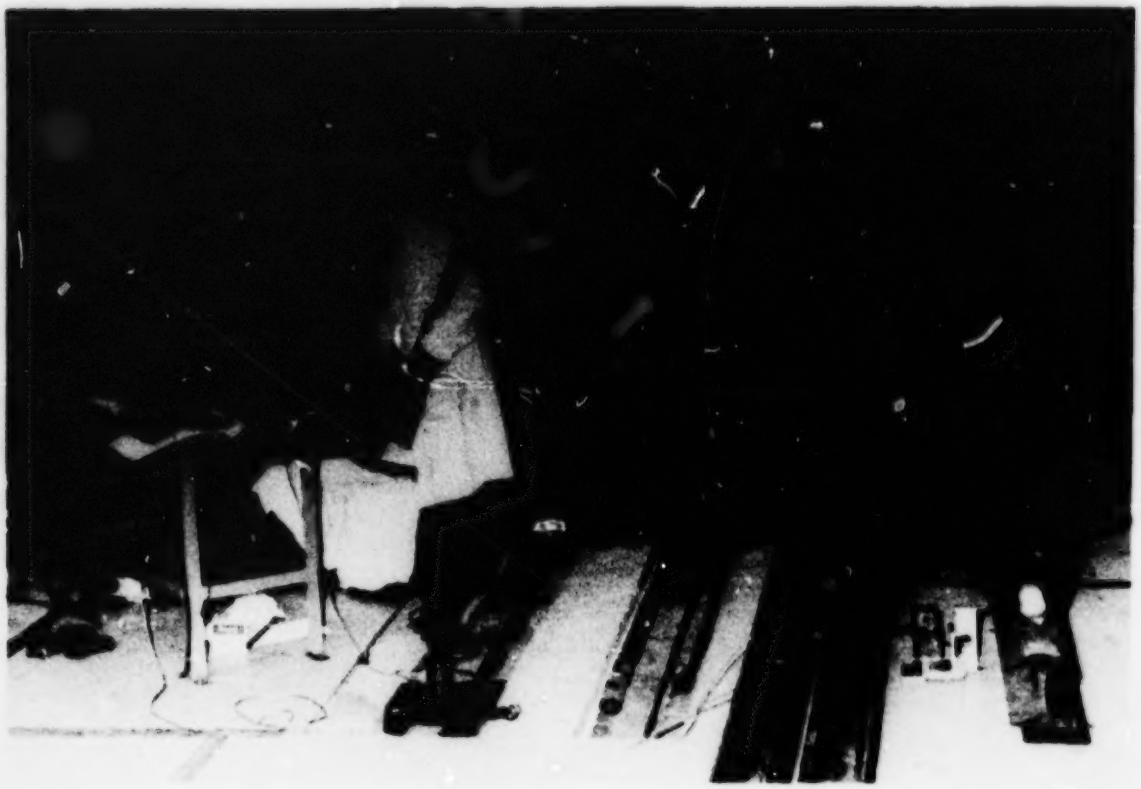


Figure 5. Bending Test of an Alternative I Worn Rail Catenary Mast, in the Plane of Maximum Flexural Rigidity. The load is applied vertically upwards.

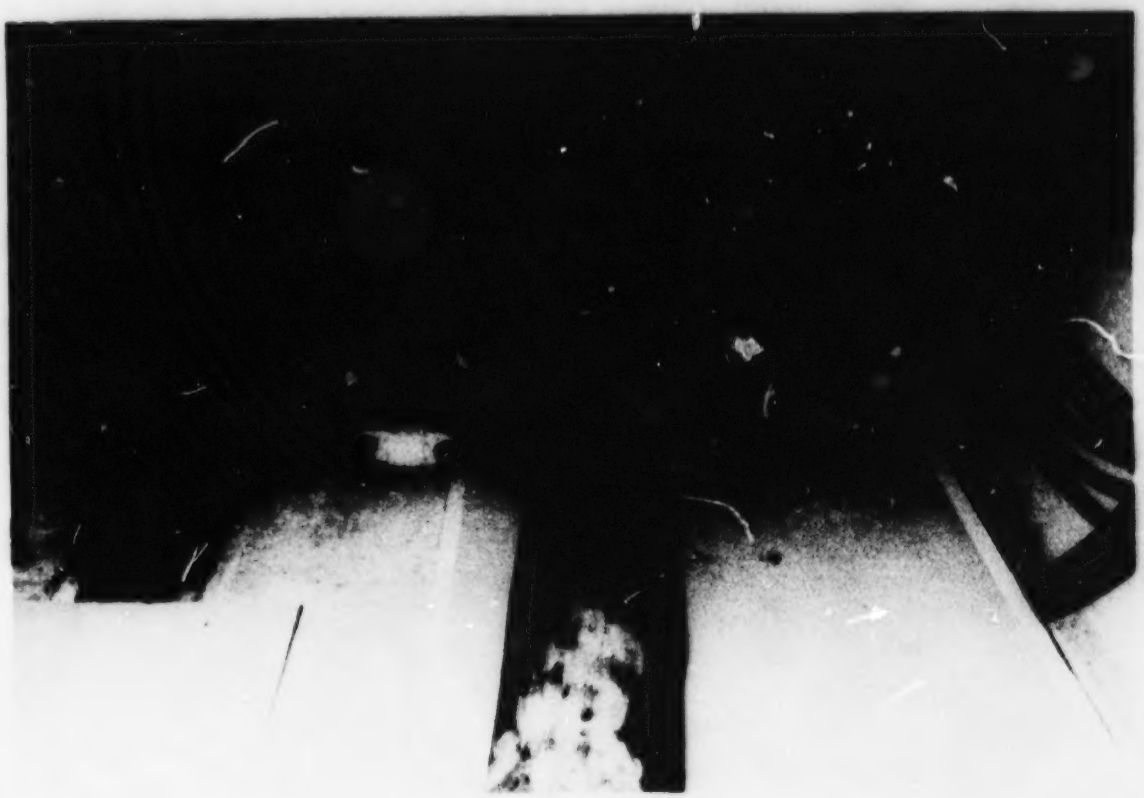


Figure 6. Horizontal Bending Test of a Wood Catenary Mast at the Overhung Configuration

Figure 7. Steel Mast Fatigue Cracks

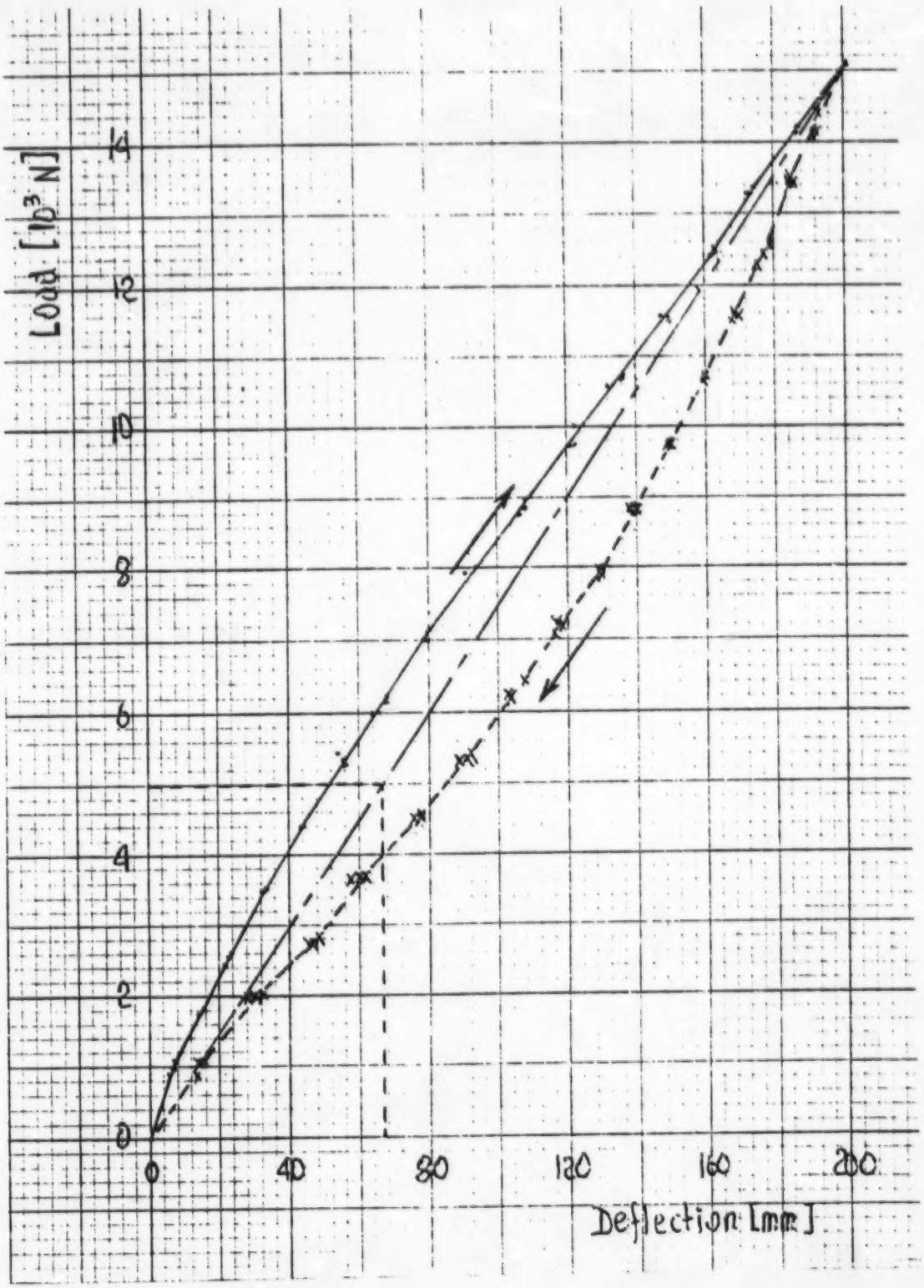


Figure 8 Deflection Curve of the Alternative I Worn Rail Catenary Mast No. 5.

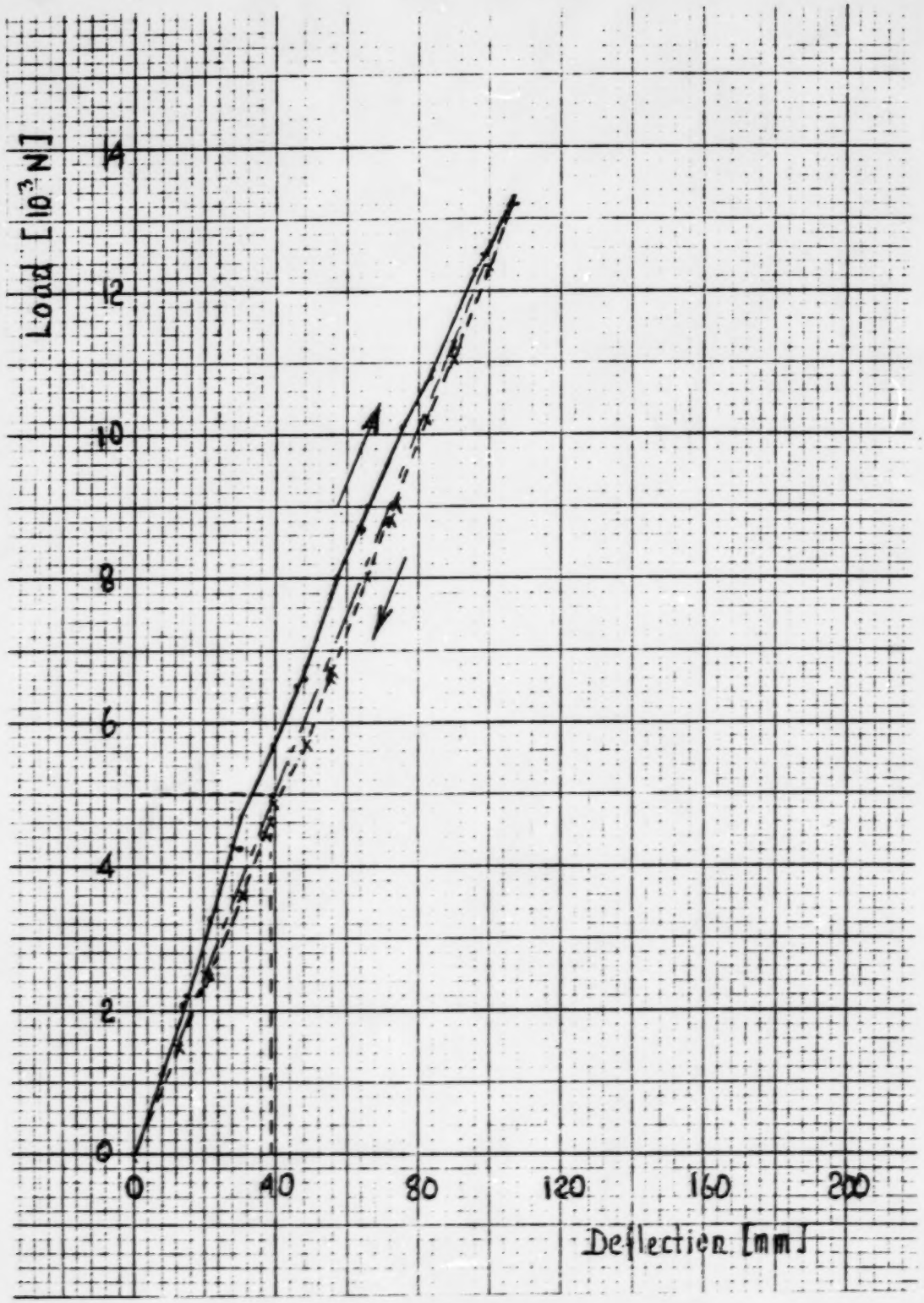
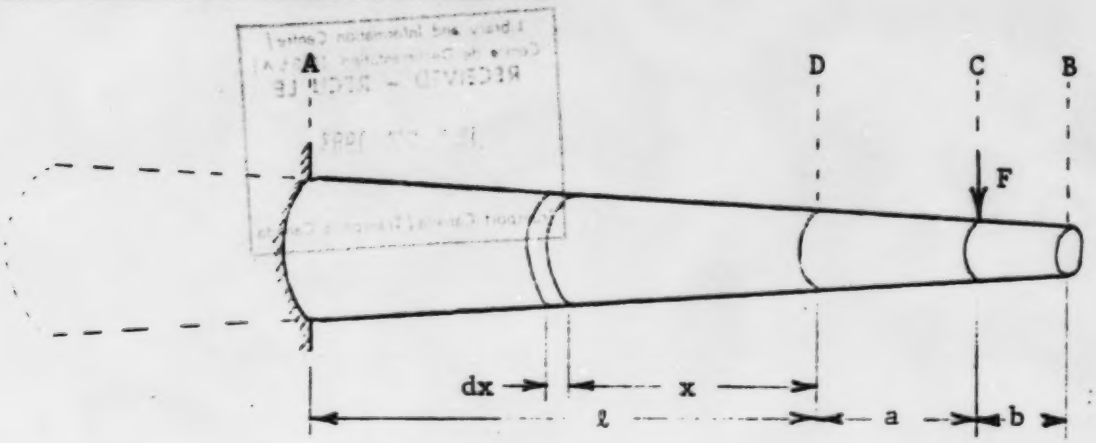


Figure 9 Deflection Curve of the Alternative II Worn Rail Catenary Mast No. 6.

DEFLECTION OF A CONICAL CANTILEVER



Deflection at point D is given by

$$\delta_D = \int_0^{\ell} \frac{1}{E \cdot I_x} \cdot x \cdot M_x \cdot dx$$

At the distance x from point D

Bending moment: $M_x = F(a+x)$

Beam diameter: $d_x = d_D + \frac{d_A - d_D}{\ell} x$

$= d_D + R \cdot x$

Moment of Intertia : $I_x = \frac{\pi \cdot d_x^4}{64}$

$= \frac{\pi (d_D + R \cdot x)^4}{64}$

Thus

$$\delta_D = \frac{64\ F}{E \cdot \pi} \left[a \int_0^{\ell} \frac{x \cdot dx}{(d_D + R.x)^4} + \int_0^{\ell} \frac{x^2 \cdot dx}{(d_D + R.x)^4} \right]$$

$$= \frac{64\ F}{E \cdot \pi \cdot R^2} \left[a \left(\frac{1}{6 d_D^2} + \frac{d_D}{3 d_A^3} - 2 \frac{1}{d_A^2} \right) + \frac{1}{R} \left(\frac{1}{3 d_D} - \frac{d_D^2}{3 d_A^3} + \frac{d_D}{d_A^2} - \frac{1}{d_A} \right) \right]$$

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